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(54) **METHOD TO INJECT HIERARCHICAL DATA ONTO SINGLE CARRIER STREAM**

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(57) **ABSTRACT**

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The present invention involves a transmitter for transmitting two levels of data in a hierarchical transmission system. The transmitter has encoders, a modulator, an adjuster, and an up converter. The first encoder has a first output and capable of providing digital information based on a first level of data on the first output. The second encoder has a second output and is capable of providing digital information based on a second level of data on the second output. The modulator is coupled to the first encoder and has I and Q outputs. The adjuster is coupled to the modulator and second encoder and modifies signals on the I and Q outputs of the modulator to produce transmission I and transmission Q outputs. The up converter is coupled to the adjuster and is capable of transmitting broadcast radio signals based on the transmission I and transmission Q outputs. The modulator may include a root raised cosine filter and/or a QPSK modulator. The I and Q outputs of the modulator include analog I and analog Q signals. The adjuster includes an inverter, a phase rotator circuit, a combiner, and/or a limiter. The transmission I and transmission Q outputs of the adjuster include analog I and analog Q signals.

**Related U.S. Application Data**

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**H04L 27/20** (2006.01)

(52) **U.S. Cl.** ..... **375/308; 332/103**

(58) **Field of Classification Search** ..... **375/242, 375/265, 269, 279, 280, 281, 295, 308; 332/103, 332/144**

See application file for complete search history.

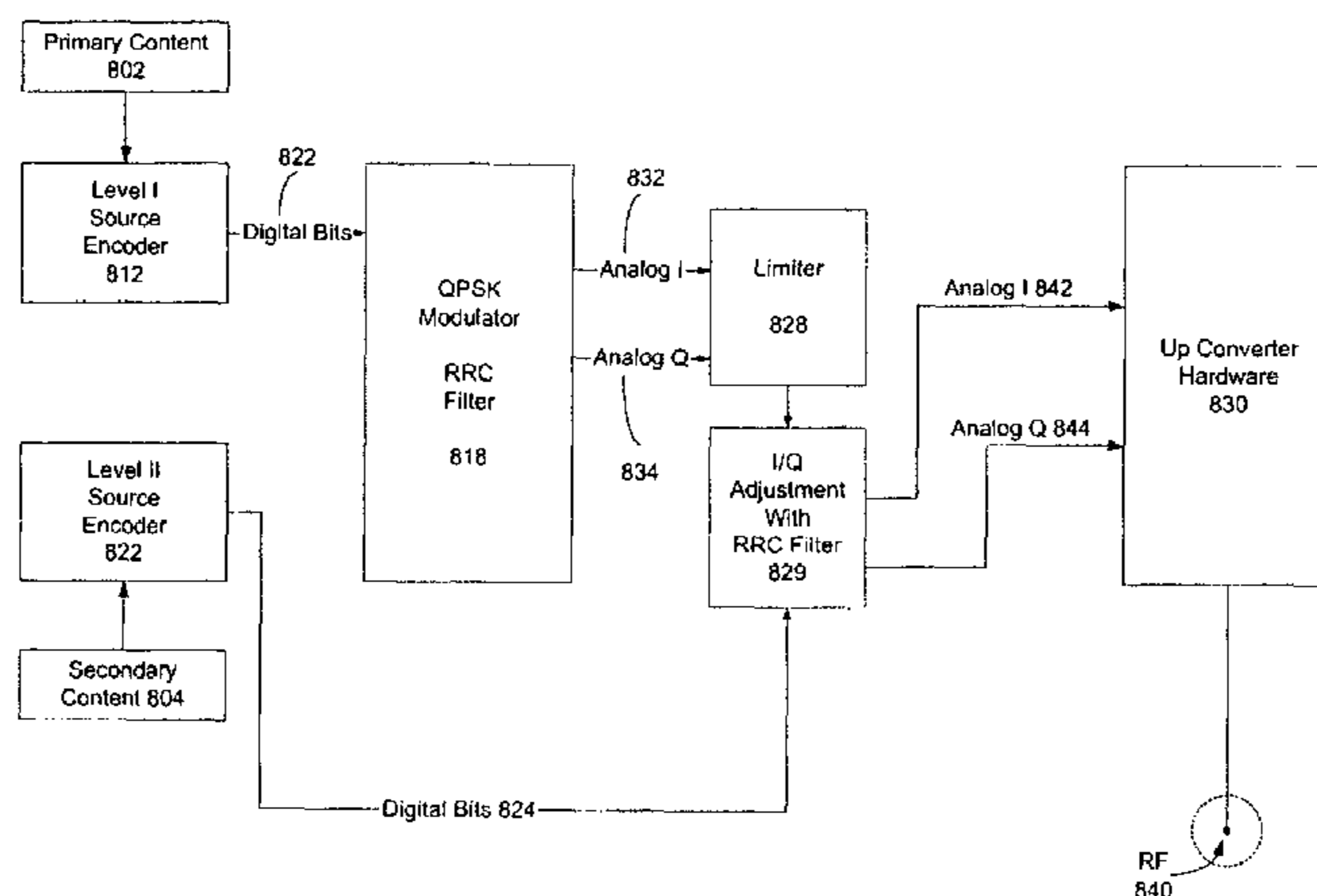
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**7 Claims, 10 Drawing Sheets**



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DVB Digital Video Broadcasting; DVB, MHP, the DVB logo and the MHP logo are registered trademarks of the Digital Video Broadcasting Project.

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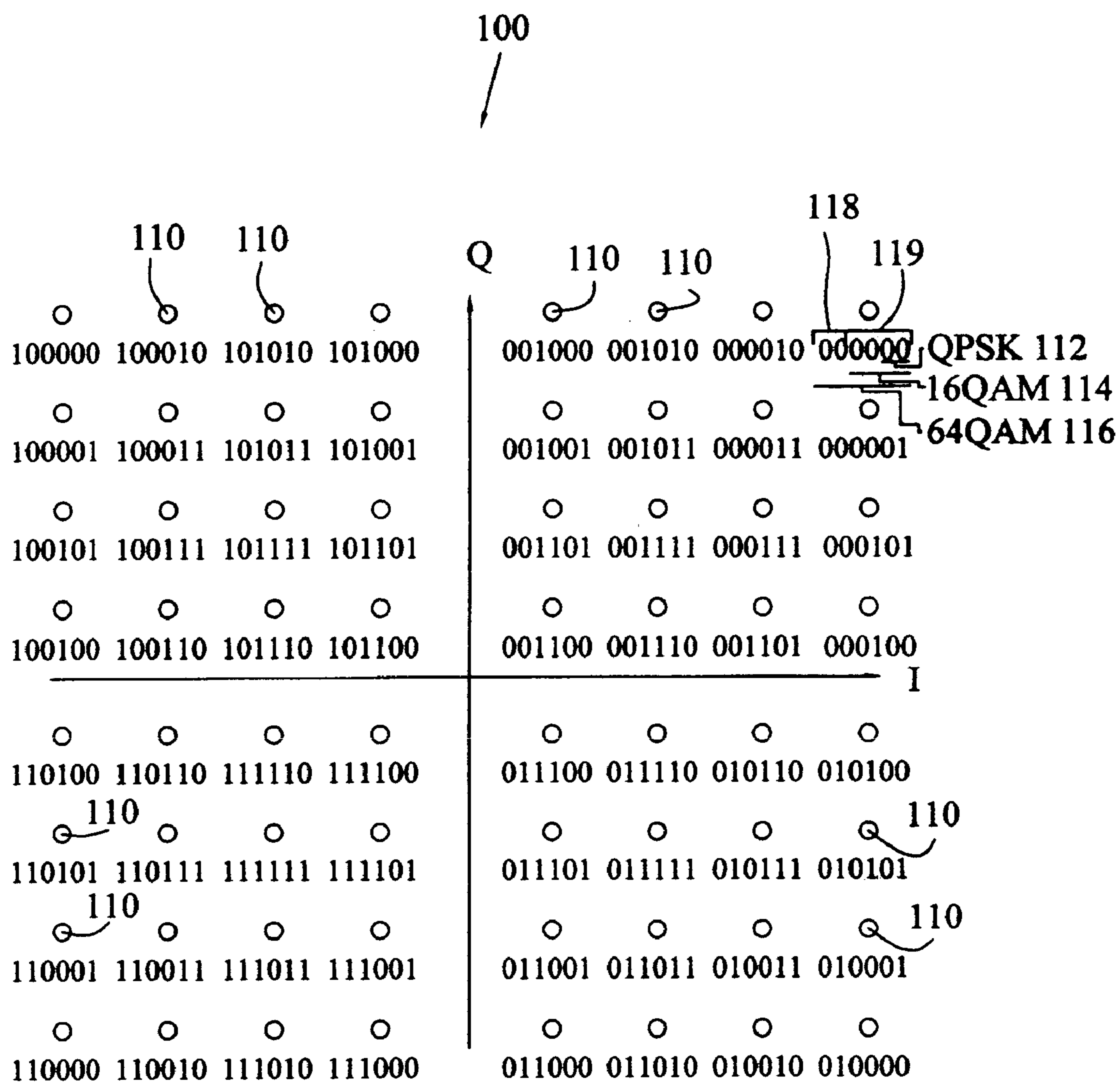


FIG. 1

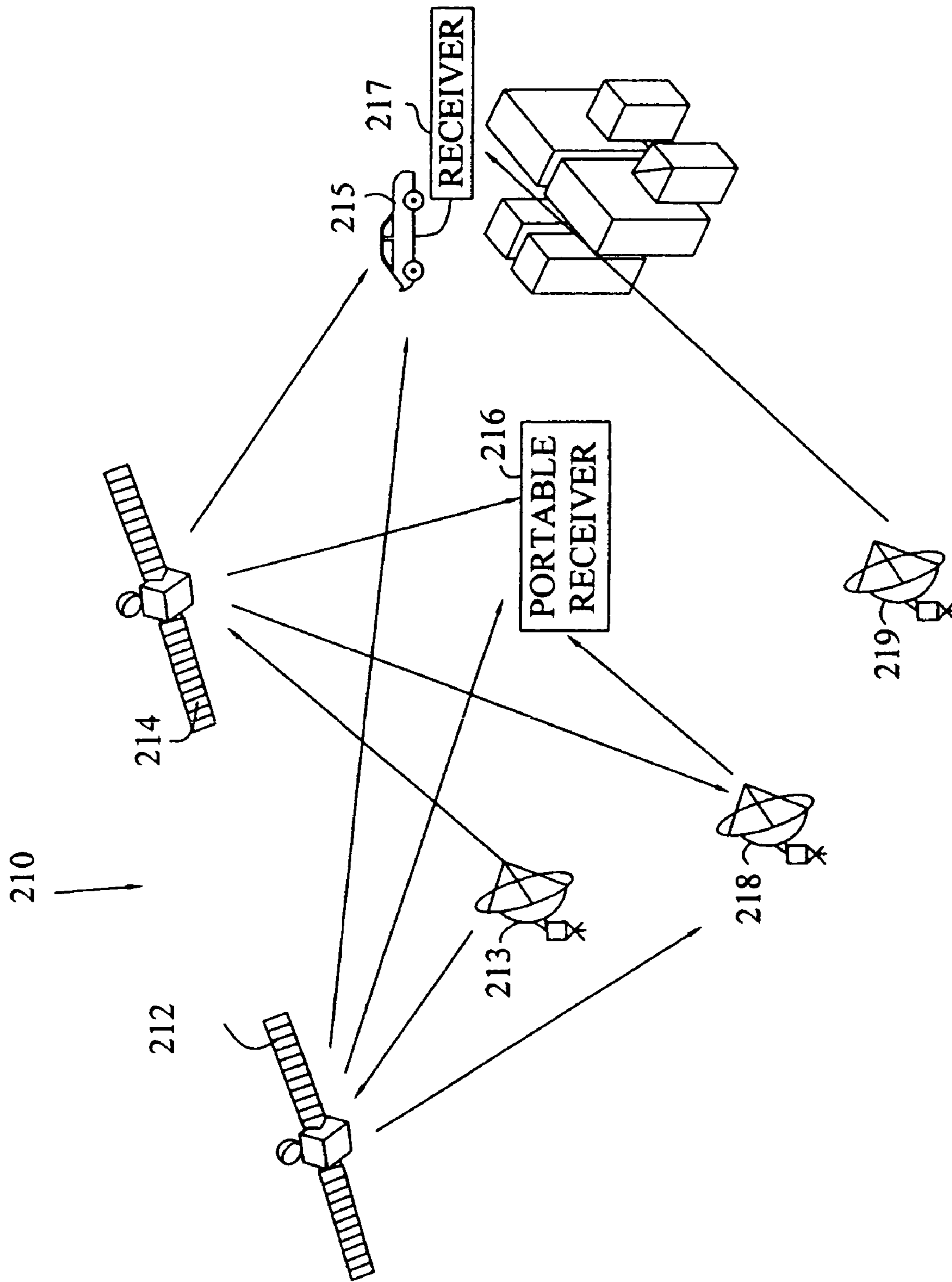


FIG. 2

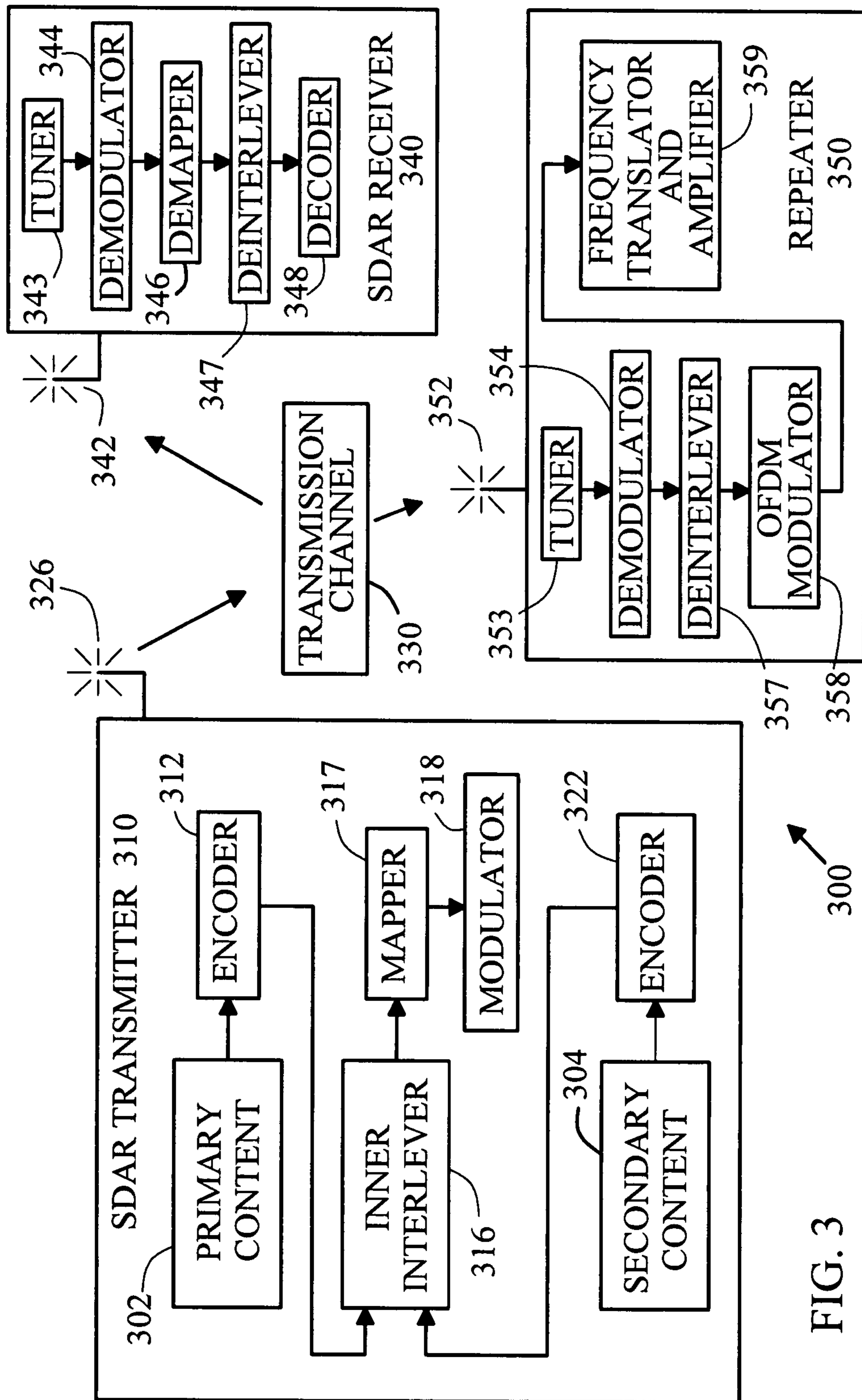


FIG. 3

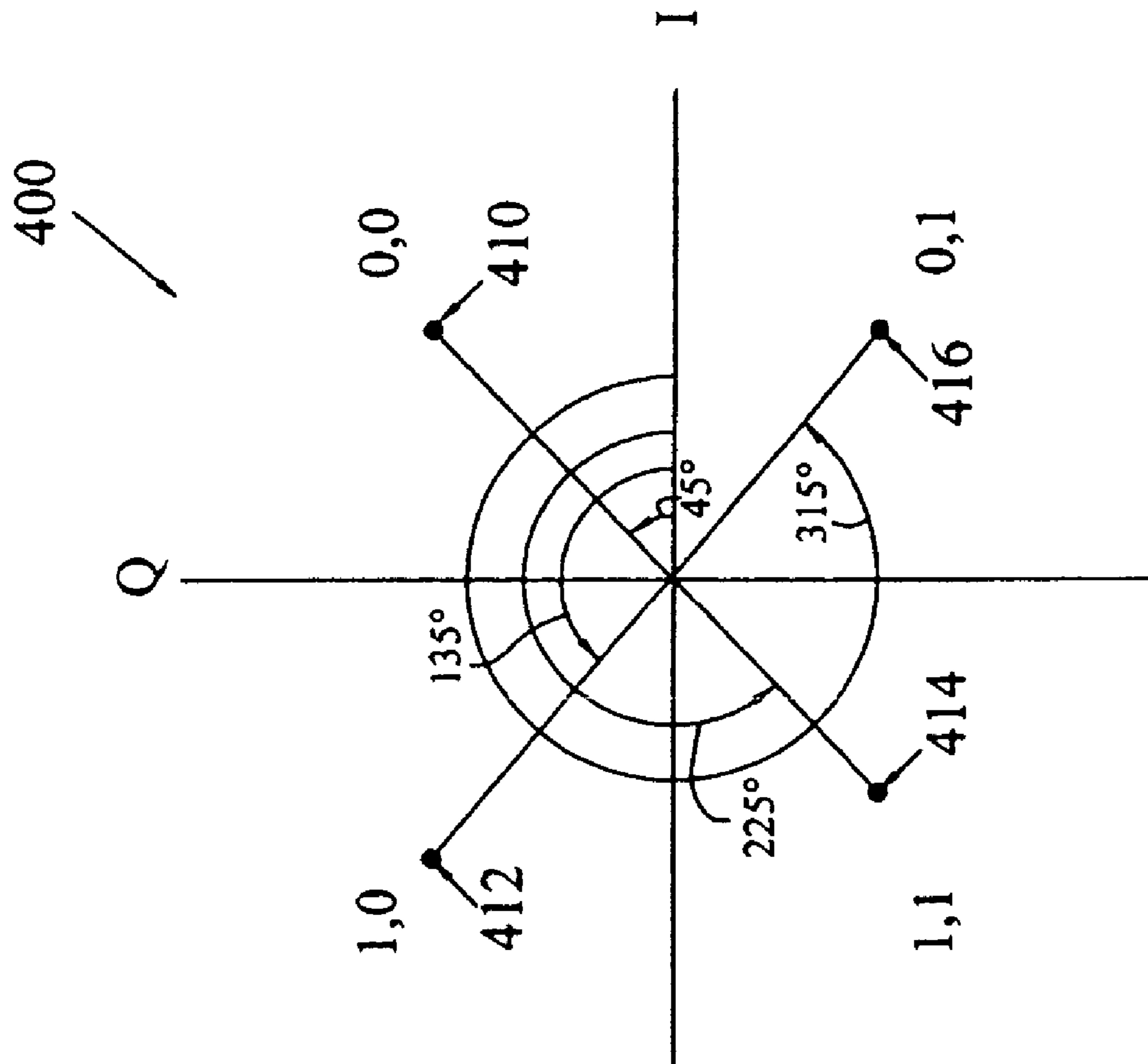


FIG. 4

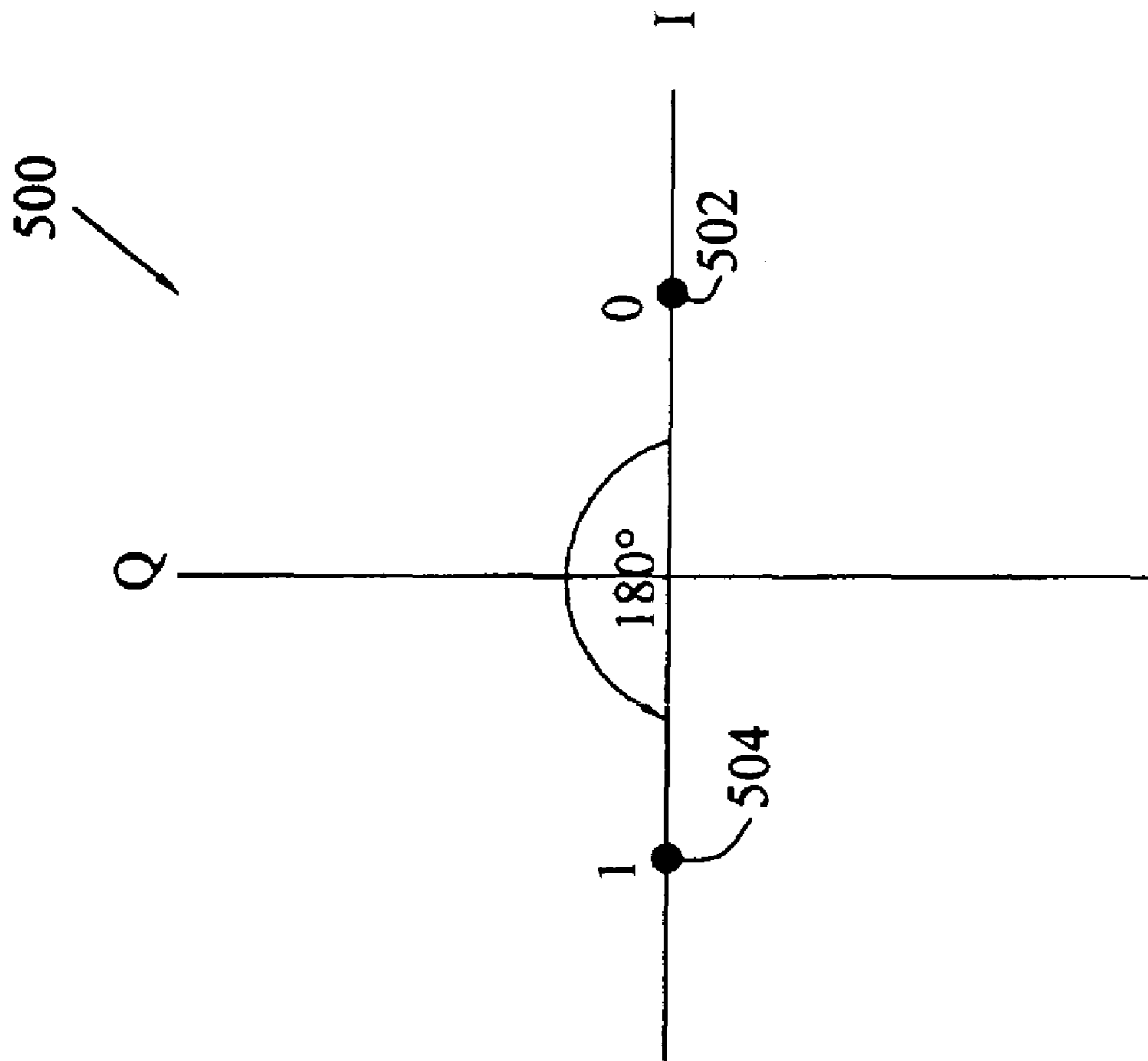


FIG. 5





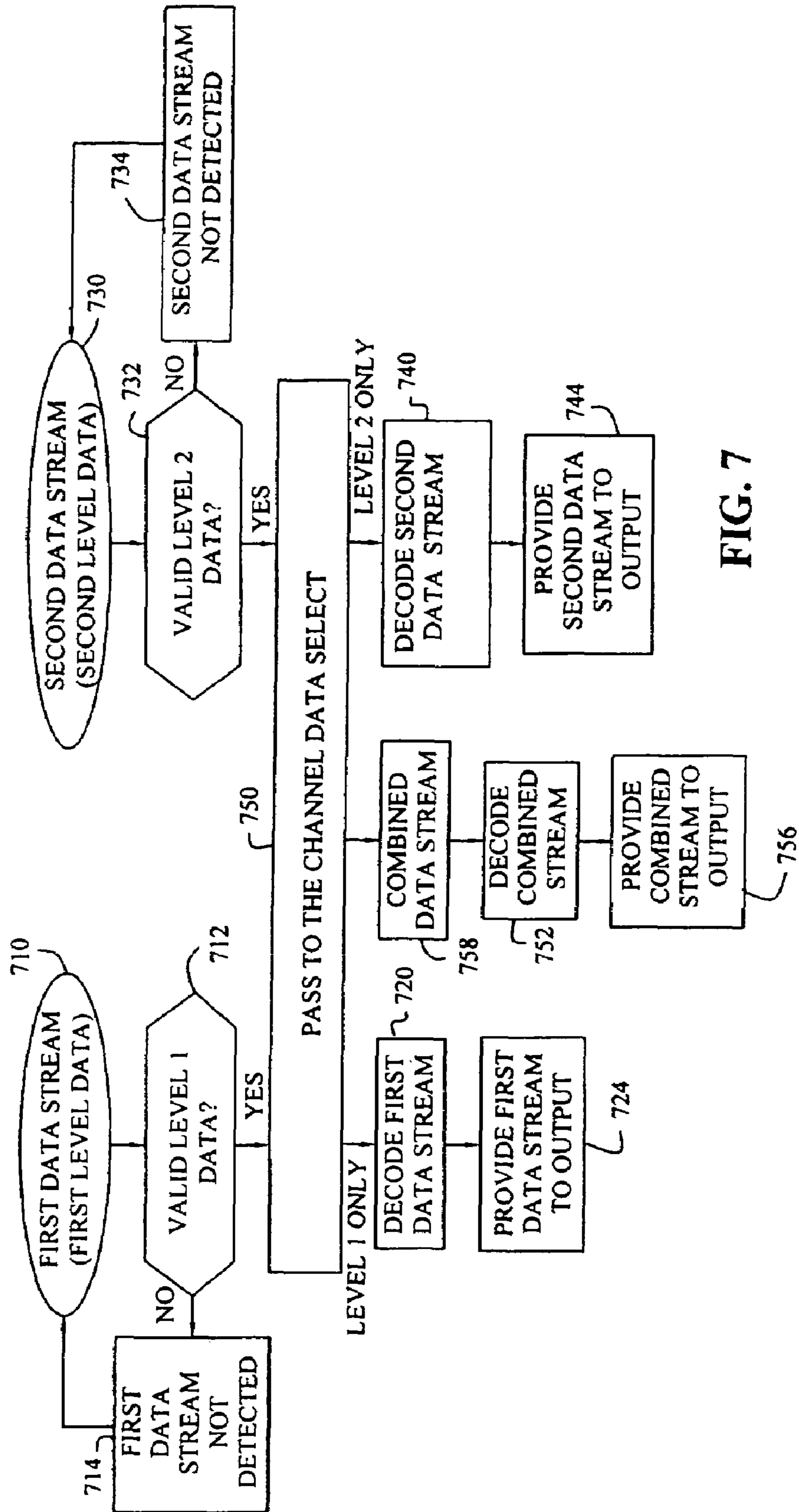


FIG. 7

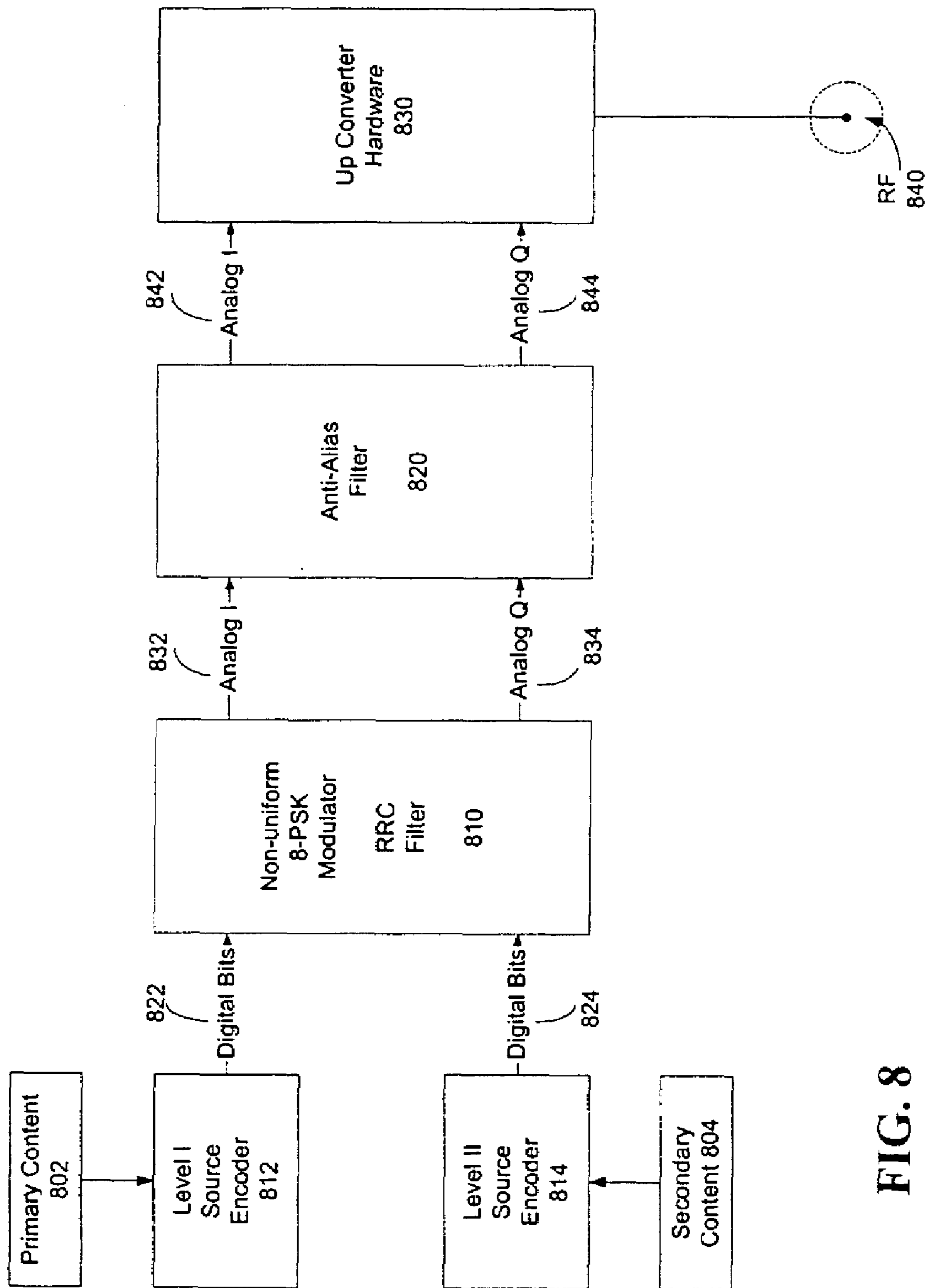


FIG. 8

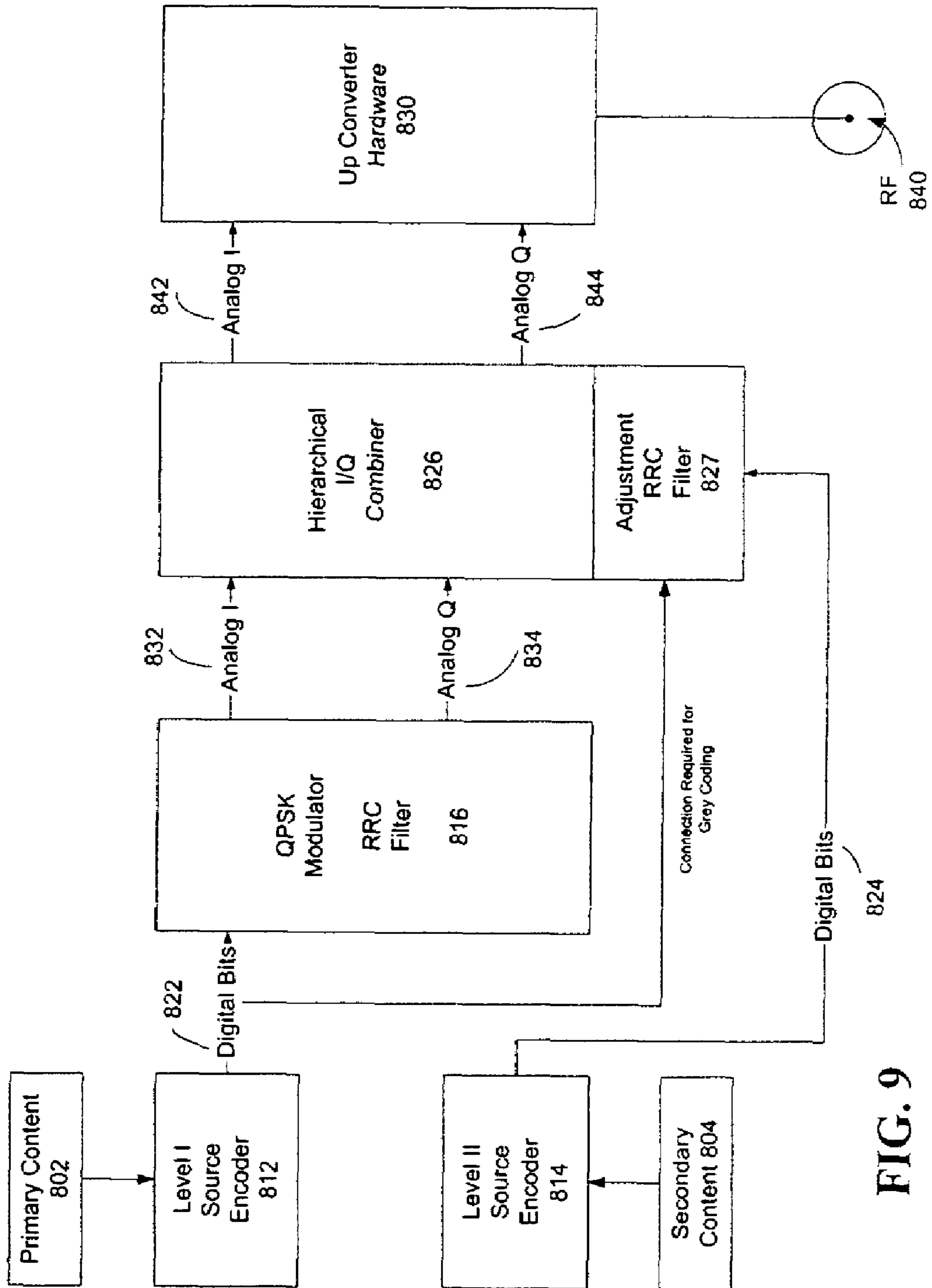


FIG. 9

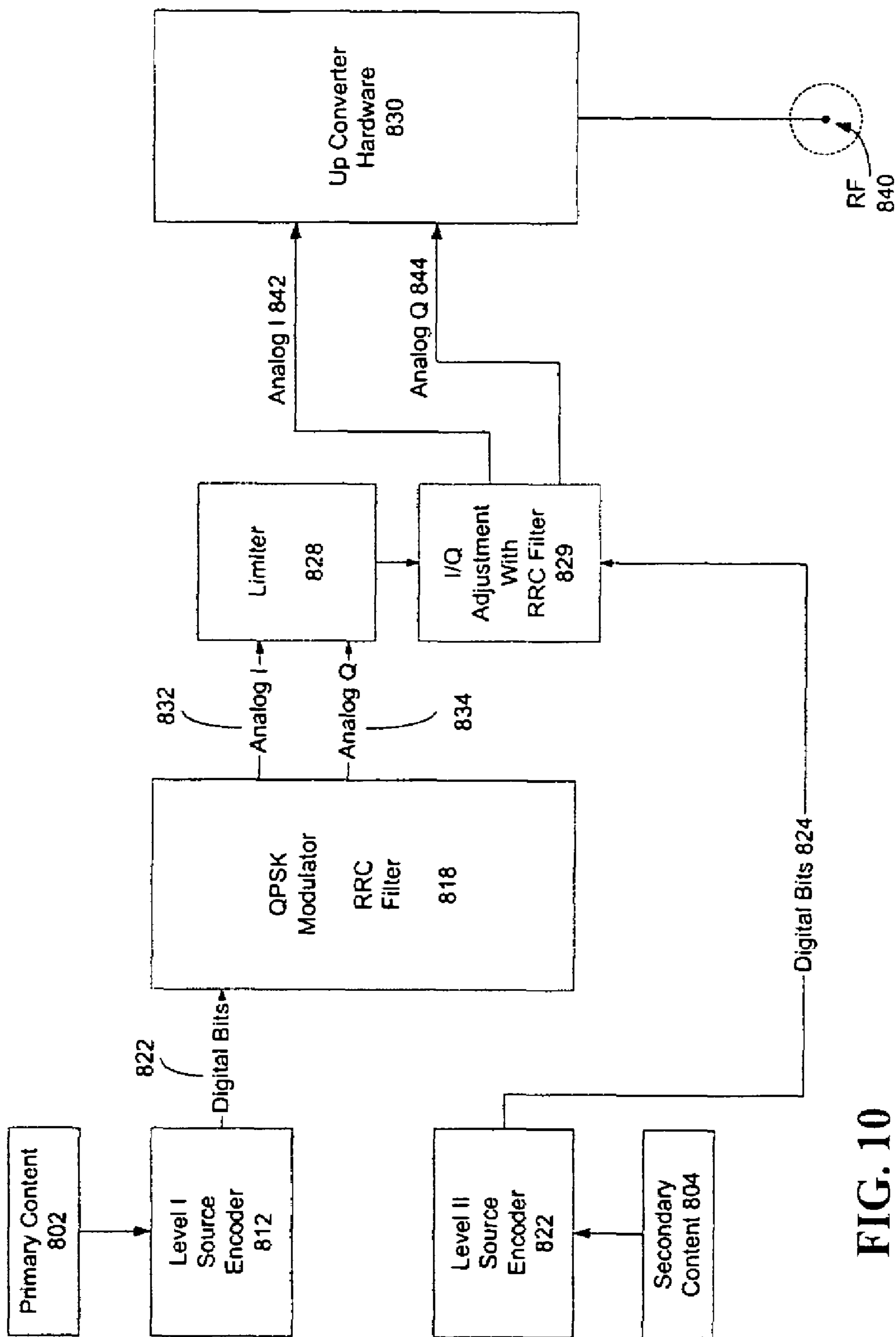


FIG. 10

## METHOD TO INJECT HIERARCHICAL DATA ONTO SINGLE CARRIER STREAM

This application claims the benefit of U.S. Provisional Patent Application No. 60/525,616 filed on Nov. 26, 2003.

### TECHNICAL BACKGROUND

The present invention generally relates to the transmission of digital data, and more particularly, to the transmission of digital data in a satellite digital audio radio (“SDAR”) system.

### BACKGROUND OF THE INVENTION

In October of 1997, the Federal Communications Commission (FCC) granted two national satellite radio broadcast licenses. In doing so, the FCC allocated twenty-five (25) megahertz (MHz) of the electromagnetic spectrum for satellite digital broadcasting, twelve and one-half (12.5) MHz of which are owned by XM Satellite Radio, Inc. of Washington, D.C. (XM), and 12.5 MHz of which are owned by Sirius Satellite Radio, Inc. of New York City, N.Y. (Sirius). Both companies provide subscription-based digital audio that is transmitted from communication satellites, and the services provided by these and other SDAR companies are capable of being transmitted to both mobile and fixed receivers on the ground.

In the XM satellite system, two (2) communication satellites are present in a geostationary orbit—one satellite is positioned at longitude 115 degrees (west) and the other at longitude eighty-five (85) degrees (east).

Accordingly, the satellites are always positioned above the same spot on the earth. In the Sirius satellite system, however, three (3) communication satellites are present that all travel on the same orbital path, spaced approximately eight (8) hours from each other. Consequently, two (2) of the three (3) satellites are “visible” to receivers in the United States at all times. Since both satellite systems have difficulty providing data to mobile receivers in urban canyons and other high population density areas with limited line-of-sight satellite coverage, both systems utilize terrestrial repeaters as gap fillers to receive and re-broadcast the same data that is transmitted in the respective satellite systems.

In order to improve satellite coverage reliability and performance, SDAR systems currently use three (3) techniques that represent different kinds of redundancy known as diversity. The techniques include spatial diversity, time diversity and frequency diversity. Spatial diversity refers to the use of two (2) satellites transmitting near-identical data from two (2) widely-spaced locations. Time diversity is implemented by introducing a time delay between otherwise identical data, and frequency diversity includes the transmission of data in different frequency bands. SDAR systems may utilize one (1), two (2) or all of the techniques.

The limited allocation of twenty-five (25) megahertz (MHz) of the electromagnetic spectrum for satellite digital broadcasting has created a need in the art for an apparatus and method for increasing the amount of data that may be transmitted from the communication satellites to the receivers in SDAR systems.

### SUMMARY OF THE INVENTION

The present invention provides an apparatus and method for increasing the amount of digital data that may be transmitted from communication satellites to receivers in

SDAR systems. In doing so, the present invention provides an advantage over the prior art. While hierarchical modulation schemes have been previously used in other data transmission applications (e.g., Digital Video-Broadcasting—Terrestrial [DVB-T] and DVB-Satellite [DVB-S] systems), until now, such hierarchical modulation schemes have not been envisioned for use in SDAR systems. By introducing the use of hierarchical modulation in SDAR systems, the present invention increases the amount of data that may be transmitted in SDAR systems and enables the enhanced performance of the receivers that receive the satellite-transmitted signals in SDAR systems.

In one form of the present invention, transmitter with encoders, a modulator, an adjuster, and an up converter is provided for transmitting two levels of data in a hierarchical transmission system. The first encoder has a first output which is capable of providing digital information based on a first level of data on the first output. The second encoder has a second output which is capable of providing digital information based on a second level of data on the second output. The modulator is coupled to said first and second encoders and has I and Q outputs. The adjuster is coupled to the modulator and modifies the signals on the I and Q outputs of the modulator, having transmission I and transmission Q outputs. The up converter is coupled to the adjuster and is capable of transmitting broadcast radio signals based on the transmission I and transmission Q outputs.

In another form of the present invention, a method for transmitting two levels of data in a hierarchical transmission system comprises the steps of: generating a signal, introducing a second level of data, transmitting the data, and detecting the data. The generating involves a first modulated signal having I and Q components based on first input data. The introducing involves a second modulation in the I and Q components of the first modulated signal based on second input data, the second modulation being separately performed on the I and Q components of the first modulated signal to generate a modified signal. Transmitting involves sending the modified signal. The detecting involves the modified signal which is performed by a first demodulation of the first modulated signal then a second demodulation to obtain the first input data and the second input data.

In still another form, the present invention provides an integrated circuit chip for enabling the use of hierarchical modulation data in a SDAR system. The integrated circuit chip comprises several components: A data generating device provides a first and a second bit stream. An encoder in electrical communication with the data generating device receives the first bit stream and encodes the first bit stream into a first transmit signal. A second encoder, also in electrical communication with the data generating device, receives the second bit stream and encodes the second bit stream into a second transmit signal. A modulator, in electrical communication with the first and second encoders, utilizes a PSK modulating scheme to modulate the first transmit signal with the second transmit signal on a carrier wave to produce a modulated transmit signal including an I-signal and a Q-signal. A magnitude adjusting device in electrical communication with the modulator adjusts the magnitude of the I and Q signals so as to adjust the phase of the transmit signal. The up-converting device up-converts the transmit signal to RF, and is in electrical communication with the magnitude adjusting device.

In yet other forms of the present invention, the modulator may include a root raised cosine filter and/or a quadrature modulator. The I and Q outputs of the modulator may

include analog I and analog Q signals. The adjuster may also include an inverter. The adjuster may alternatively include a phase rotator circuit. The transmission I and transmission Q outputs of the adjuster may include analog I and analog Q signals.

The present invention intercepts the analog I/Q bit stream prior to up conversion, allowing for the additional secondary data to be added by adjusting the magnitude of the I and Q channels to adjust the phase. This may be done prior to a root raised cosine filter. The modified I and Q channels are then upconverted with a conventional upconverter.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The above-mentioned and other features and objects of this invention, and the manner of attaining them, will become more apparent and the invention itself will be better understood by reference to the following description of embodiments of the invention taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is an illustrative view of a constellation chart for 64-quadrature amplitude modulation (QAM) with an embedded quadrature phase shift keying (QPSK) stream;

FIG. 2 is a diagrammatic view of a SDAR system implementing a method of the present invention;

FIG. 3 is a block diagram of a SDAR communication system adapted to enable a method of the present invention;

FIG. 4 is a diagrammatic view of a QPSK constellation;

FIG. 5 is a diagrammatic view of a binary phase shift keying (BPSK) constellation;

FIG. 6 is a diagrammatic view of a hierarchical 8-PSK constellation;

FIG. 7 is a flow chart illustrating a method of the present invention as utilized in a SOAR receiver;

FIG. 8 is a schematic diagram of an alternative version of a SDAR transmitter capable of use in the system of FIG. 3; and

FIGS. 9 and 10 are schematic diagrams of additional alternative versions of a SDAR transmitter capable of use in the system of FIG. 3.

Corresponding reference characters indicate corresponding parts throughout the several views. Although the drawings represent embodiments of the present invention, the drawings are not necessarily to scale and certain features may be exaggerated in order to better illustrate and explain the present invention. The exemplifications set out herein illustrate embodiments of the invention in several forms and such exemplification is not to be construed as limiting the scope of the invention in any manner.

#### DESCRIPTION OF INVENTION

The embodiments disclosed below are not intended to be exhaustive or limit the invention to the precise forms disclosed in the following detailed description. Rather, the embodiments are chosen and described so that others skilled in the art may utilize their teachings.

For the purposes of the present invention, certain terms shall be interpreted in accordance with the following definitions.

“Feed forward correction” is a method of improving secondary data (defined infra) detection. By knowing the relative “I” (in-phase) and “Q” (quadrature) components of a constellation quadrant, the detector may be enhanced to perform better by having a priori knowledge to assist detection.

“First level data” and/or “primary data” hereinafter refers to existing data that may be interpreted by current (i.e., “legacy”) SDAR receivers. Because the first level data can be interpreted by the legacy receivers, the first level data may also be considered to have backwards compatibility.

“Hierarchical modulation” hereinafter describes when two separate data or bit streams are modulated onto a single data stream. Essentially, an additional data stream is superimposed upon, mapped on, or embedded within the primary data transmission. The additional data stream may have a different data rate than the primary data stream. As such, the primary data is more susceptible to noise than it would be in a non-hierarchical modulation scheme. By using a different coding algorithm, the usable data of the additional stream may be transmitted with a different level of error protection than the primary data stream. Broadcasters of SDAR services may use the additional and primary data streams to target different types of receivers, as will be explained below.

“Legacy receiver” hereinafter describes a current or existing SDAR receiver that is capable of interpreting first level data. Legacy receivers typically interpret second level data as noise.

“Second generation receiver” hereinafter describes a SDAR receiver that contains hardware and/or software enabling the receiver to interpret second level data (e.g., demodulator enhancements). Second generation receivers may also interpret first level data.

“Second level data”, “secondary data” and/or “hierarchical data” hereinafter refers to the additional data that is superimposed on the first level data to create a hierarchically modulated data stream. Second level data may be interpreted by SDAR receivers containing the appropriate hardware and/or software to enable such interpretation (i.e., “second generation” receivers). Second level, or secondary, data may perform differently from first level, or primary, data.

QAM is one form of multilevel amplitude and phase modulation that is often employed in digital data communication systems. Using a two-dimensional symbol modulation composed of a quadrature (orthogonal) combination of two (2) pulse amplitude modulated signals, a QAM system modulates a source signal into an output waveform with varying amplitude and phase. Data to be transmitted is mapped to a two-dimensional, four-quadrant signal space, or constellation. The QAM constellation employs “I” and “Q” components to signify the in-phase and quadrature components, respectively. The constellation also has a plurality of phasor points, each of which represent a possible data transmission level. Each phasor point is commonly called a “symbol,” represents both I and Q components and defines a unique binary code. An increase in the number of phasor points within the QAM constellation permits a QAM signal to carry more information.

Many existing systems utilize QPSK modulation systems. In such QPSK systems, a synchronous data stream is modulated onto a carrier frequency before transmission over the satellite channel, and the carrier can have four (4) phase states, e.g., 45 degrees, 135 degrees, 225 degrees or 315 degrees. Thus, similar to QAM, QPSK employs quadrature modulation where the phasor points can be uniquely described using the I and Q axes. In contrast to QAM, however, the pair of coordinate axes in QPSK can be associated with a pair of quadrature carriers with a constant amplitude, thereby creating a four (4) level constellation, i.e., four (4) phasor points having a phase rotation of 90 degrees. Differential quadrature phase shift keying (D-QPSK) refers to the procedure of generating the trans-

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mitted QPSK symbol by calculating the phase difference of the current and the preceding QPSK symbol. Therefore, a non-coherent detector can be used for D-QPSK because it does not require a reference in phase with the received carrier.

Hierarchical modulation, used in DVB-T systems as an alternative to conventional QPSK, 16-QAM and 64-QAM modulation methods, may better be explained with reference to FIG. 1. FIG. 1 illustrates 64-QAM constellation 100. Each permissible digital state is represented by phasors 110 in the I/Q plane. Since eight (8) by eight (8) different states are defined, sixty-four (64) possible values of six (6) bits may be transmitted in 64-QAM constellation 100. FIG. 1 shows the assignment of binary data values to the permissible states. In a 16-QAM constellation, there are four (4) by four (4) different states and four (4) transmitted bits, in a 4-PSK constellation, there are two (2) by two (2) states and two (2) transmitted bits, and in a BPSK constellation, there is one (1) state and one (1) transmitted bit.

In systems employing hierarchical modulation schemes, the possible states are interpreted differently than in systems using conventional modulation techniques (e.g., QPSK, 16-QAM and 64-QAM). By treating the location of a state within its quadrant and the number of the quadrant in which the state is located as a priori information, two separate data streams may be transmitted over a single transmission channel. While 64-QAM constellation 100 is still being utilized to map the data to be transmitted, it may be interpreted as the combination of a 16-QAM and a 4-PSK modulation. FIG. 1 shows how 64-QAM constellation 100, upon which is mapped data transmitted at six (6) bits/symbol 116, may be interpreted as including QPSK constellation 112 (which includes mapped data transmitted at two (2) bits/symbol) combined with 16-QAM constellation 114 (which includes mapped data transmitted at four (4) bits/symbol). The combined bit rates of QPSK and the 16-QAM data streams is equal to the bit rate of the 64-QAM data stream.

In systems employing hierarchical modulation schemes, one (1) data stream is used as a secondary data stream while the other is used as a primary data stream. The secondary data stream typically has a lower data rate than the primary stream. Again referring to FIG. 1, using this hierarchical modulation scheme, the two (2) most significant bits 118 may be used to transmit the secondary data to second generation receivers while the remaining four (4) bits 119 may be used to code the primary data for transmission to the legacy receivers.

The present invention contemplates the use of hierarchical modulation in a SDAR system, while maintaining backward compatibility for legacy receivers. Shown in FIG. 2 is a diagrammatic view of a SDAR system in which a hierarchical modulation scheme is employed. SDAR system 210 includes first and second communication satellites 212, 214, which transmit line-of-sight signals to SDAR receivers 216, 217 located on the earth's surface. A third satellite may be included in other SDAR systems. Satellites 212, 214, as indicated above, may provide for spatial, frequency and time diversity. As shown, receiver 216 is a portable receiver such as a handheld radio or wireless device. Receiver 217 is a mobile receiver for use in vehicle 215. SDAR receivers 216, 217 may also be stationary receivers for use in a home, office or other non-mobile environment.

SDAR system 210 further includes a plurality of terrestrial repeaters 218, 219. Terrestrial repeaters 218, 219 receive and retransmit the satellite signals to facilitate reliable reception in geographic areas where the satellite signals

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are obscured from the view of receivers 216, 217 by obstructions such as buildings, mountains, canyons, hills, tunnels, etc. The signals transmitted by satellites 212, 214 and terrestrial repeaters 218, 219 are received by receivers 216, 217, which either combine or select one of the signals as receiver's 216, 217 output.

FIG. 3 illustrates a block diagram of a SDAR communication system in which hierarchical modulation is utilized. In an exemplary embodiment of the present invention, SDAR communication system 300 includes SDAR transmitter 310, SDAR receiver 340 and terrestrial repeater 350. As in conventional SDAR communication systems, SDAR communication system 300 will input data content 302, 304 and perform processing and frequency translation within transmitter 310. The digital data is transmitted over transmission channel 330 to receiver 340 or terrestrial repeater 350. Generally, receiver 340 performs the converse operations of transmitter 310 to recover data 302, 304. Repeater 350 generally re-transmits data 302, 304 to receiver 340. Unlike conventional SDAR communication systems, however, transmitter 310, receiver 340 and repeater 350 of the present invention provide hardware enabling SDAR communication system 300 to utilize a hierarchical modulation scheme to transmit and receive more digital data than conventional systems.

SDAR transmitter 310 includes encoders 312, 322. The audio, video, or other form of digital content to be transmitted comprises primary input signal 302 and secondary input signal 304, which are typically arranged as series of k-bit symbols. Primary input signal 302 contains primary, or first level, data and secondary input signal 304 contains secondary, or second level, data. Encoders 312, 322 encode the k bits of each symbol as well as blocks of the k-bit symbols. In other embodiments of the present invention, separate encoders may be used to encode the blocks of k-bit symbols, for example, outer and inner encoders. In an exemplary embodiment of the present invention, encoder 312 may encode primary data stream 302 using a block or a convolutional forward error correction (FEC) algorithm, and encoder 322 may encode secondary data stream 304 using a turbo coding algorithm or a low density parity check FEC algorithm. It is contemplated that other FEC encoding methods may be utilized to encode primary and secondary data streams 302, 304, including, for example, Hamming codes, cyclic codes and Reed-Solomon (RS) codes.

Again referring to FIG. 3, inner interleaver 316 multiplexes encoded secondary content data stream 304 with encoded primary content data stream 302 to form a transmit data stream. This transmit data stream is passed to mapper 317, which maps the data stream into symbols composed of I and Q signals. Mapper 317 may be implemented as a look-up table where sets of bits from the transmit signal are translated into I and Q components representing constellation points or symbols. FIG. 6 is representative of an exemplary embodiment of the present invention, in which a hierarchical modulation scheme is employed and the constellation points are in accordance with either a uniform or non-uniform 8-PSK constellation 600, where each phasor is represented by a three (3) bit symbol composed of I and Q signals.

FIG. 4 shows QPSK constellation 400 for primary data having two (2) transmitted bits/symbol. Phasors "00", "10", "11", "01" correlate to a phase of 45 degrees, a phase of 135 degrees, a phase of 225 degrees and a phase of 315 degrees, respectively. FIG. 5 shows BPSK constellation 500 for secondary data having one (1) transmitted bit/symbol. Phasors "0" and "1" correlate to a phase of zero (0) and 180

degrees, respectively. When a secondary data symbol is added onto a primary data symbol, constellation **600** of FIG. **6** is illustrative of the resulting hierarchical modulation.

Constellation **600** may be perceived as two (2) sets of superimposed modulations—QPSK constellation **400** transmitting two (2) bits/symbol **620** combined with BPSK constellation **500** comprising one (1) bit/symbol. The first modulation is the primary QPSK data, which is represented by “x” marks **620**, **622**, **624**, **626**. In order to superimpose the secondary data onto the primary data, the primary QPSK data is phase offset by the additional, secondary data, which is represented by any of data points **601**, **602**, **603**, **604**, **605**, **606**, **607**, **608** depending on the phase offset. Positive phase offsets include phasors **602**, **604**, **606** and **608**, and negative phase offsets include **601**, **603**, **605** and **607**.

Shown in FIG. **6**, phase offset **610** is the offset angle relative to the QPSK symbol. As explained above, a typical QPSK constellation contains 45 degree, 135 degree, 225 degree and 315 degree points. The hierarchical data is represented by a phase offset relative to those four (4) degree points, and the phase offsets with the four (4) degree points represent a hierarchical (8-PSK) constellation. A uniform 8-PSK constellation is created when offset angle **610** is 22.5 degrees. Every other offset angle **610** creates a non-uniform 8-PSK constellation. For example, as shown in FIG. **6**, a 15 degree phase offset relative to primary data phasors **620**, **622**, **624**, **626** produces a phase offset correlative to phasors **601** (“000”) or **602** (“001”), **603** (“101”) or **604** (“100”), **605** (“110”) or **606** (“111”), and **607** (“011”) or **608** (“010”), respectively. Gray coding is a method which may be used to make the bit assignments for the hierarchical constellation. For example, reference is made to the secondary data bit (b2). Instead of making b2=0 a negative offset and b2=1 a positive offset, the hierarchical constellation may be configured so as to increase the bit error rate (BER) performance (e.g., b2=1 can be made a negative offset).

The amount of the phase offset is equal to the amount of power in the secondary signal. The amount of energy in the secondary signal may not be equal to the amount of energy in the primary signal. As phase offset **610** is increased, the energy in the secondary data signal is also increased. The performance degradation to the primary data signal is minimized by the perceived coding gain improvement as phase offset **610** is increased. The application of the hierarchical phase modulation on top of an existing QPSK signal containing primary data causes phase offset **610** to adjust either positively or negatively relative to the hierarchical data.

In general, a secondary data bit causes either a larger Q magnitude and smaller I magnitude or a larger I magnitude and smaller Q magnitude. With FEC techniques utilized in encoders **312**, **322**, the I and Q signals are used in conjunction with each other over a block of data. These techniques give the appearance that the primary data bits are spread over time, enabling the secondary data to appear somewhat orthogonal to the primary data bits. Indeed, it has been shown in simulations that the secondary data’s impact on the primary data is somewhat orthogonal. For example, for a twenty (20) degree phase offset for secondary data, the primary data has a one (1) decibel (dB) degradation when using a rate  $\frac{1}{3}$  convolutional code with a constraint length of seven (7), followed by a (255, 223) RS block code (8 bits/symbol). However, when the primary data has no FEC coding, the impact of the twenty (20) degree phase offset is 4.1 dB. This data demonstrates a perceived coding improvement of 3.1 dB in the case where phase offset **610** is set to twenty (20) degrees.

Again referring to FIG. **3**, the FEC coding technique implemented by encoders **312**, **322** spreads the primary and secondary data over many QPSK symbols, which essentially spreads the energy over time and the I and Q bits. To overcome the unequal signal-to-noise ratio (“Eb/No”) between primary data bits and secondary data bits, the amount of phase offset **610** may be increased until the performance of the primary data is equal to the performance of the secondary data. However, as phase offset **610** is increased, legacy receivers may have a difficult time acquiring and tracking the desired primary data signal. By spreading the second level bits over multiple symbols, spread spectrum coding techniques may be used to increase the amount of energy in the secondary bits. This allows phase offset **610** to be adjusted and made more compatible with legacy receivers. Additionally, the use of second level data spreading reduces overall second level data throughput. Overall, several techniques may be utilized to maximize the performance of the secondary data. These techniques include: increasing phase offset **610** to maximize the secondary data energy per symbol; using multiple symbols per secondary data bit; using more complex FEC algorithms, and using a beam steering antenna to improve the performance of the secondary data (e.g., a higher gain directional antenna for stationary reception and a pointing/steering antenna for mobile reception).

Referring back to FIG. **3**, after mapper **317** translates encoded and interleaved primary and secondary data streams **302**, **304**, respectively, into I and Q components, the I and Q components are modulated by modulator **318**. Modulation enables both primary data stream **302** and secondary data stream **304** to be transmitted as a single transmission signal via antenna **326** over single transmission channel **330**. Primary data stream **302** is modulated with secondary data stream **304** using one of a number of modulation techniques, including amplitude or phase and may include differential or coherent modulation (for example, BPSK, QPSK, differential Q-PSK (D-QPSK) or pi/4 differential QPSK (pi/4 D-QPSK)). According to the technique that modulator **318** employs, modulator **318** may be any of amplitude or phase modulator. Each modulation technique is a different way of transmitting the data across channel **330**. The data bits are grouped into pairs, and each pair is represented by a symbol, which is then transmitted across channel **330** after the carrier is modulated.

An increase in the capacity of the transmitted signal would not cause backwards compatibility problems with legacy receivers as long as the legacy receivers may interpret the first level data. Second generation receivers, however, are capable of interpreting both first and second level data. Techniques may be employed to minimize the degradation in the legacy receiver, including decreasing phase offset **610** to limit the amount of the second level data energy per symbol, limiting the amount of time over which the second level data is transmitted, and making the second level data energy appear as phase noise to the legacy receiver.

Referring back to FIG. **2**, after modulator **318** modulates first data stream **302** and second level data stream **304** (FIG. **3**) to create a transmission signal, transmitter **213** uplinks the transmission signal to communication satellites **212**, **214**. Satellites **212**, **214**, having a “bent pipe” design, receive the transmitted hierarchically modulated signal, performs frequency translation on the signal, and re-transmits, or broadcasts, the signal to either one or more of plurality of terrestrial repeaters **218**, **219**, receivers **216**, **217**, or both.

As shown in FIG. **3**, terrestrial repeater **350** includes terrestrial receiving antenna **352**, tuner **353**, demodulator



354, de-interleaver 357, modulator 358 and frequency trans-  
 lator and amplifier 359. Demodulator 354 is capable of  
 down-converting the hierarchically modulated downlinked  
 signal to a time-division multiplexed bit stream, and de-  
 interleaver 357 re-encodes the bit-stream in an orthogonal  
 frequency division multiplexing (OFDM) format for terres-  
 trial transmission. OFDM modulation divides the bit stream  
 between a large number of adjacent subcarriers, each of  
 which is modulated with a portion of the bit stream using  
 one of the M-PSK, differential M-PSK (D-MPSK) or dif-  
 ferential pi/4 M-PSK (pi/4 D-MPSK) modulation tech-  
 niques. Accordingly, if a hierarchically modulated signal is  
 transmitted to one or both terrestrial repeaters 218, 219  
 (FIG. 2), terrestrial repeaters 218, 219 receive the signal,  
 decode the signal, re-encode the signal using OFDM modu-  
 lation and transmit the signal to one or more receivers 216,  
 217. Because the signal contains both the first and second  
 level data, the terrestrial signal maintains second level data  
 bit spreading over multiple symbols.

Also shown in FIG. 3, SDAR receiver 340 contains  
 hardware (e.g., a chipset) and/or software to process any  
 received hierarchically modulated signals as well. Receiver  
 340 includes one or more antennas 342 for receiving signals  
 transmitted from either communication satellites 212, 214,  
 terrestrial repeaters 218, 219, or both (FIG. 2). Receiver 340  
 also includes tuner 343 to translate the received signals to  
 baseband. Separate tuners may be used to downmix the  
 signals received from communication satellites 212, 214 and  
 the signals received from terrestrial repeaters 218, 219. It is  
 also envisioned that one tuner may be used to downmix both  
 the signals transmitted from communication satellites 212,  
 214 and the signals transmitted from repeaters 218, 219.

Once the received signal is translated to baseband, the  
 signal is demodulated by demodulator 344 to produce the I  
 and Q components. De-mapper 346 translates the I and Q  
 components into encoded primary and secondary data  
 streams. These encoded bit streams, which were interleaved  
 by interleaver 316, are recovered by de-interleaver 347 and  
 passed to decoder 348. Decoder 348 employs known bit and  
 block decoding methods to decode the primary and second-  
 ary bit streams to produce the original input signals con-  
 taining the primary and secondary data 302, 304. In other  
 embodiments of the present invention, multiple decoders  
 may be used, e.g., outer and inner decoders. Receiver 340  
 may also use a feed forward correction technique to improve  
 its detection of the secondary data. By knowing the relative  
 I/Q quadrant, receiver 340 may be enhanced to perform  
 better by having such a priori knowledge, which assists in  
 the detection of the transmitted signal. For example, refer-  
 ring to FIG. 6, if it is known from a priori first level data  
 knowledge that symbol 602 or 601 was transmitted at some  
 point in time, and the received symbol lands at 604, it can  
 be inferred by minimum distance that the received second  
 level data bit is a weak one (1) by utilizing feed forward  
 correction. However, without feed forward correction the  
 second level data bit would have been detected as a strong  
 zero (0). Therefore, feed forward detection utilizes the  
 decoded symbol with the detected offset (either positive or  
 negative) to determine the secondary data bit.

In another embodiment of the present invention, a method  
 of enabling extra data bits from a hierarchical modulation  
 scheme to be used to transmit additional data for each  
 channel in a SDAR system is contemplated. A flow chart  
 illustrating this embodiment of the present invention as  
 utilized in an SDAR communication system is shown in  
 FIG. 7. It is contemplated that the inventive method would  
 be carried out by a receiver adapted to be used in a SDAR

system. The receiver may concurrently process the receipt of  
 first data stream 710 and second data stream 730. If first data  
 stream 710 is valid as determined by error checking at step  
 712, first data stream 710 is passed to a channel data select  
 at step 750. If first data stream 710 is selected and second  
 data stream 730 is either independent or not valid, only first  
 data stream 710 is decoded at step 720 at its original rate,  
 e.g., forty-eight (48) kbps. The decoded data from first data  
 stream 710 is then passed to an output unit at step 724.

If second data stream 730 is valid as determined by error  
 checking at step 732, then second data stream 730 is passed  
 to the channel data select at step 750. If second data stream  
 730 is selected and is independent from first data stream 710,  
 only second data stream 730 is decoded at step 740 at its  
 original rate, e.g., sixteen (16) kbps. The decoded data from  
 second data stream 730 is then passed to an output unit at  
 step 744.

If the receiver determines at step 712 that first data stream  
 710 is valid and at step 732 that second data stream 730 is  
 valid, both data streams are passed to the channel data select  
 at step 750. The channel data select determines if second  
 data stream 730 is an enhancement to first data stream 710.  
 Audio enhancements may include audio quality enhance-  
 ments, audio coding enhancements such as 5.1 audio (i.e., a  
 Dolby® AC-3 digital audio coding technology in which 5.1  
 audio channels [left, center, right, left surround, right sur-  
 round and a limited-bandwidth subwoofer channel] are  
 encoded on a bit-rate reduced data stream), data/text addi-  
 tions, album pictures, etc. If second data stream 730 is an  
 enhancement to first data stream 710, the channel data select  
 combines the two (2) data streams such that the combined  
 signal has a data rate greater than the first data stream's 710  
 data rate, e.g., 64 kbps. Thus, the sixteen (16) kbps data rate  
 of second data stream 730 acts to increase the rate of first  
 data stream 710 from forty-eight (48) kbps to sixty-four (64)  
 kbps. Combined data stream 758 is then decoded at step 752  
 and passed to an output unit at step 756. In an exemplary  
 embodiment, when switching from first data stream 710 to  
 combined data stream 758, the increase in data rate is  
 blended so as not to enable a quick change between first data  
 stream 710 and combined data stream 758. If second data  
 stream 730 is determined to be invalid, the channel data  
 select switches to a "first data level" only implementation  
 and sends first data stream 710 to be decoded at step 720.  
 The data rate of first data stream 710 remains at its original  
 forty-eight (48) kbps. In an exemplary embodiment of this  
 inventive method, a decrease in data rate is blended so as not  
 to enable a quick change between first data stream 710 and  
 combined data stream 758. Assuming that second data  
 stream 730 becomes or remains valid, the receiver decodes  
 combined data stream 758 at step 752 and provides com-  
 bined data stream 758 to an output unit at step 756.

Another aspect of the present invention involves an  
 alternative form of SDAR transmitter shown in FIG. 8.  
 Transmitter 800 is provided primary content 802 and sec-  
 ondary content 804 which supply input data to Level I  
 source encoder 812 and Level II source encoder 814, respec-  
 tively. Digital bits 822, 824 from encoders 812 and 814 are  
 input to non-uniform 8-PSK modulator and root raised  
 cosine (RRC) filter 810 to be converted to analog I and Q  
 signals 832 and 834, respectively, that are input to anti-alias  
 filter 820. Anti-alias filter 820 performs the operation nec-  
 essary to provide analog I and analog Q signals 842, 844 that  
 become the correct hierarchical transmission I and Q signals  
 that are ultimately transmitted by up converter 830 as  
 broadcast radio frequency signal (or RF) 840. While the  
 circuit of FIG. 8 involves PSK modulation, other suitable

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modulation techniques such as those disclosed above may be used in modulator **810** to implement the present invention.

In another embodiment of an SDAR transmitter, illustrated in FIG. **9**, wherein digital bits **822** are input to QPSK modulator and RRC filter **816** and Adjustment RRC filter **827**, which is coupled with hierarchical I/Q combiner **826**. Adjustment RRC filter **827** then causes hierarchical I/Q combiner **826** to adjust analog I and Q signals **832**, **834** to have the appropriate analog I and Q signals **842**, **844** to be upconverted and broadcast as describe above. Adjustment RRC filter **827** creates an I and complementary Q signal (based on the Digital Bit **824**) that when combined with inputs **832** and **834** create the desired hierarchical signal. Adjustment RRC filter **827** may accept input Digital Bits **822** when a Grey coded hierarchical transmission is desired. RRC filter **827** is the same filter structure used in Modulator **816**. This Adjustment RRC filter **827** creates the I and complementary Q signal that is equal to the subtraction of Analog I and Q (**832**, **834**) signals from the Analog I and Q (**842**, **844**). To simplify the figure, Anti-alias Filter **820** is incorporated into Up Converter Hardware **830**. Unlike the architecture of FIG. **8**, the FIG. **9** architecture allows the existing legacy hardware to be used with only minor changes.

Another embodiment of an SDAR transmitter according to the present invention is depicted in FIG. **10**. QPSK modulator and RRC filter **818** receives primary data via digital bits **822** and provides analog I and Q signals **832**, **834** to limiter **828** (legacy modulator). Limiter **828** provides Digital Bits (delayed version of Digital bits **822**) to I/Q adjustment with RRC filter **829** which also receives the secondary data via digital bits **824**. After adjustment, analog I and Q signals **842**, **844** are upconverted and broadcast as described above. The architecture of FIG. **10** can used with minimal changes to the legacy hardware. I/Q Adjustment with RRC **829** is the same implementation as FIG. **8**. block **810**.

While this invention has been described as having an exemplary design, the present invention may be further modified within the spirit and scope of this disclosure. This application is therefore intended to cover any variations,

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uses, or adaptations of the invention using its general principles. Further, this application is intended to cover such departures from the present disclosure as come within known or customary practice in the art to which this invention pertains.

We claim:

1. A transmitter for transmitting two levels of data in a hierarchical transmission system comprising:
  - a first encoder having a first output and capable of providing digital information based on a first level of data on said first output;
  - a second encoder having a second output and capable of providing digital information based on a second level of data on said second output;
  - a modulator coupled to said first encoder and having I and Q outputs;
  - an adjuster coupled to said modulator and said second encoder and modifying signals on said I and Q outputs of said modulator, said adjuster having transmission I and transmission Q outputs; and
  - an up converter coupled to said adjuster and capable of transmitting broadcast radio signals based on said transmission I and transmission Q outputs.
2. The transmitter of claim **1** wherein said modulator includes a root raised cosine filter.
3. The transmitter of claim **1** wherein said modulator includes a QPSK modulator.
4. The transmitter of claim **1** wherein said I and Q outputs of said modulator include analog I and analog Q signals.
5. The transmitter of claim **1** wherein said adjuster includes a root raised cosine filter coupled to at least one of said first and second outputs.
6. The transmitter of claim **1** further comprising a limiter coupling said I and Q outputs of said modulator to said adjuster.
7. The transmitter of claim **1** wherein said transmission I and transmission Q outputs of said adjuster include analog I and analog Q signals.

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